Characterization of aeolian dust in Antarctic ice cores

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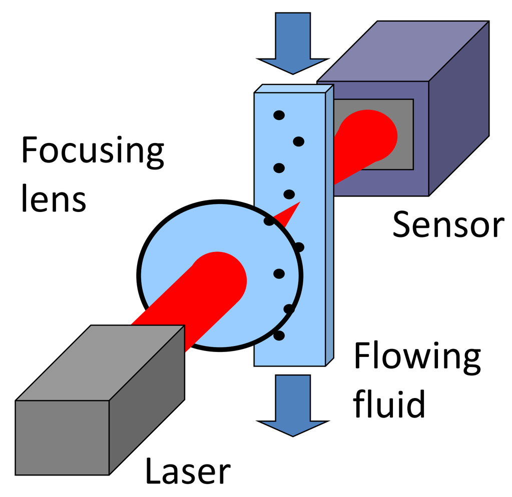
Abstract

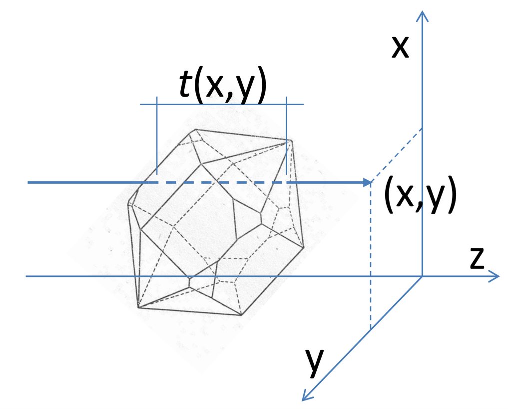
Mineral dust aerosol is widely recognized as a fundamental component of the climate system and is closely coupled with glacial-interglacial climate oscillations of the Quaternary period. However, the direct impact of dust on the energy balance of the Earth system remains poorly quantified, mainly because of uncertainties in dust radiative properties, which vary greatly over space and time. Here we provide the first direct measurements of the aerosol optical thickness of dust particles windblown to central East Antarctica (Dome C) during the last glacial maximum (LGM) and the Holocene. By applying the Single Particle Extinction and Scattering (SPES) technique and imposing preferential orientation to particles, we derive information on shape from samples of a few thousands of particles. These results highlight that clear shape variations occurring within a few years are hidden to routine measurement techniques. With this novel measurement method the optical properties of airborne dust can be directly measured from ice core samples, and can be used as input into climate model simulations. Based on simulations with an Earth System Model we suggest an effect of particle non-sphericity on dust aerosol optical depth (AOD) of about 30% compared to spheres, and differences in the order of ~10% when considering different combinations of particles shapes.

SPES:

Simultaneous measurement of the **extinction cross section** and the **optical thickness** of single particles passing thorugh a focused laser beam

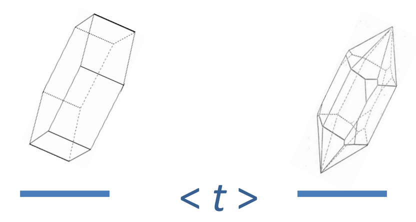


Laser diode, λ= 635 nm
Focal spot d = 10 µm
Cell thickness 200 µm
Water flow 30 cc/min

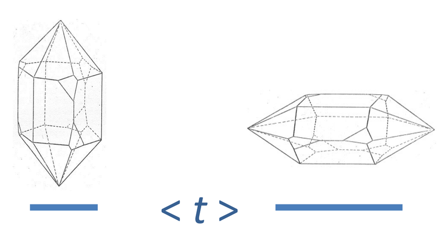


Averaging the geometrical thickness $t(x,y)$ over the whole particle gives $< t >$.

By introducing the particle refractive index n, we derive the average optical thickness $\rho = < t > (n - 1)$

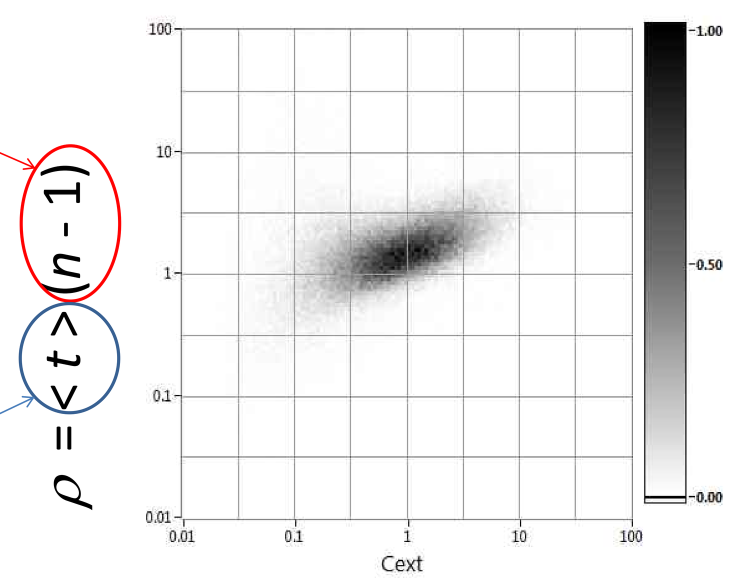


Comparable $< t >$, different n $\Rightarrow$ different ρ



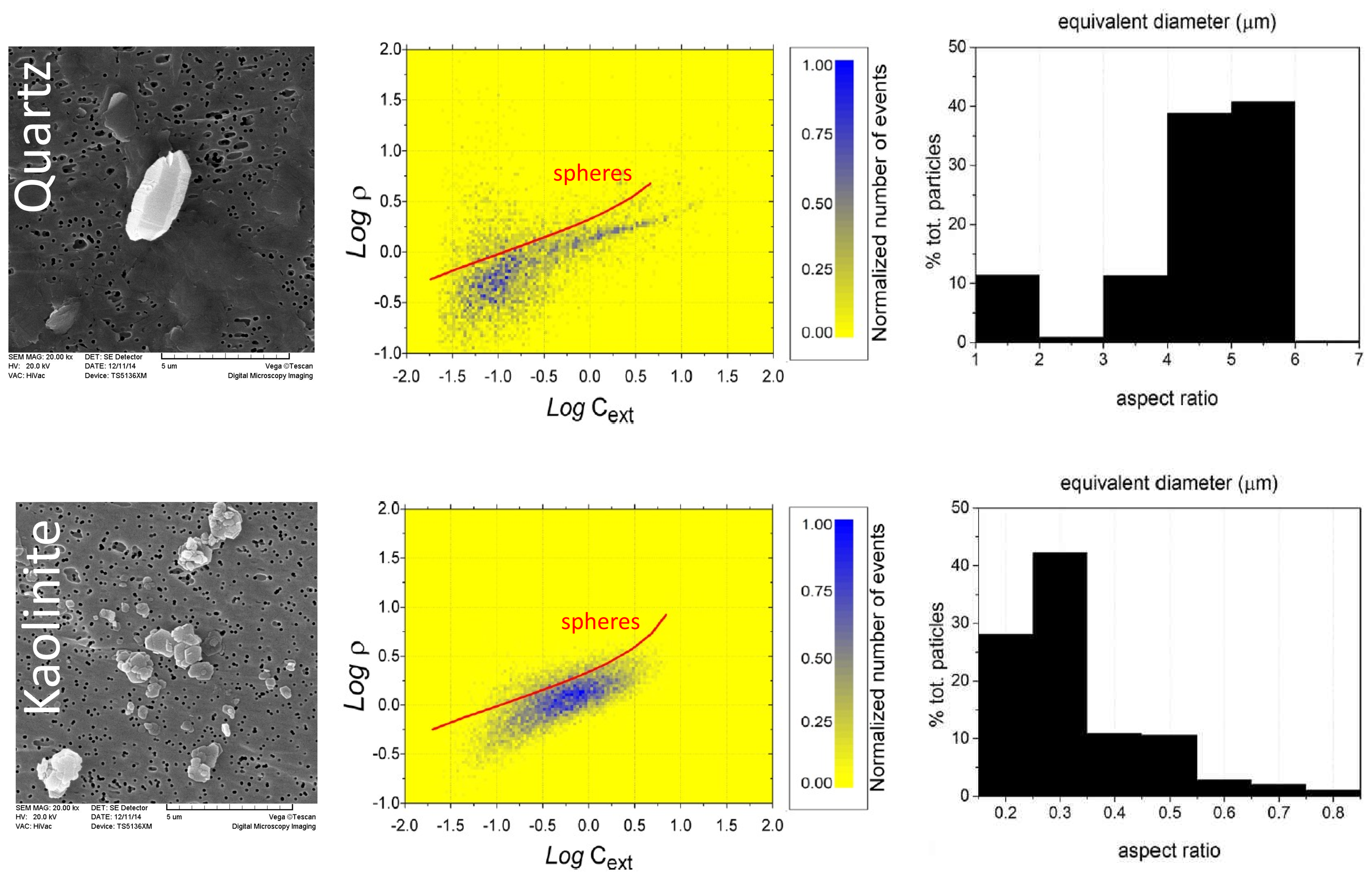
Different $< t >$, same n $\Rightarrow$ different ρ

2D SPES diagram for data obtained with kaolinite polydisperse powder



Commercially available extinction technique (ABACUS) allows meaurements of C_{ext} only

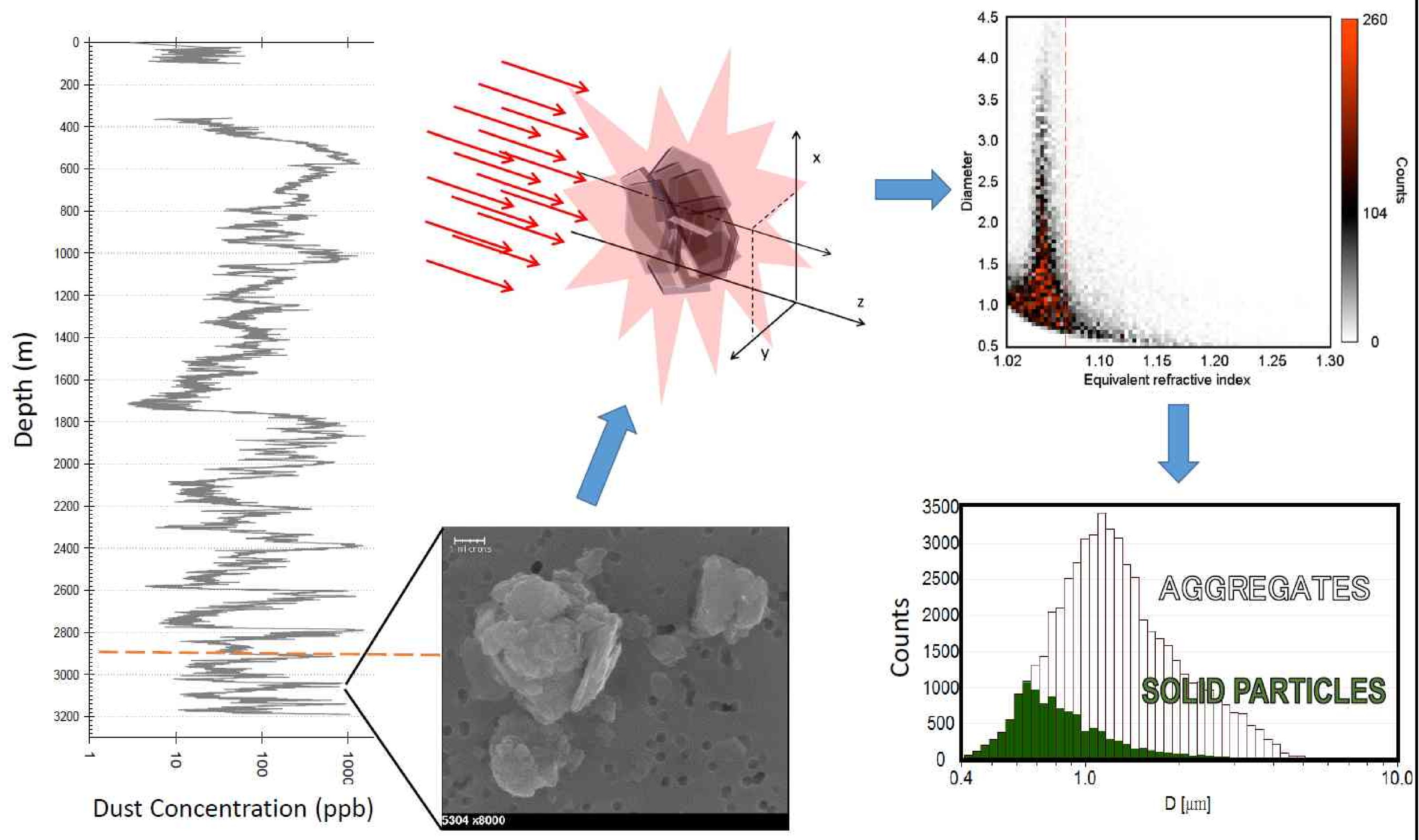
Measuring particle aspect ratios



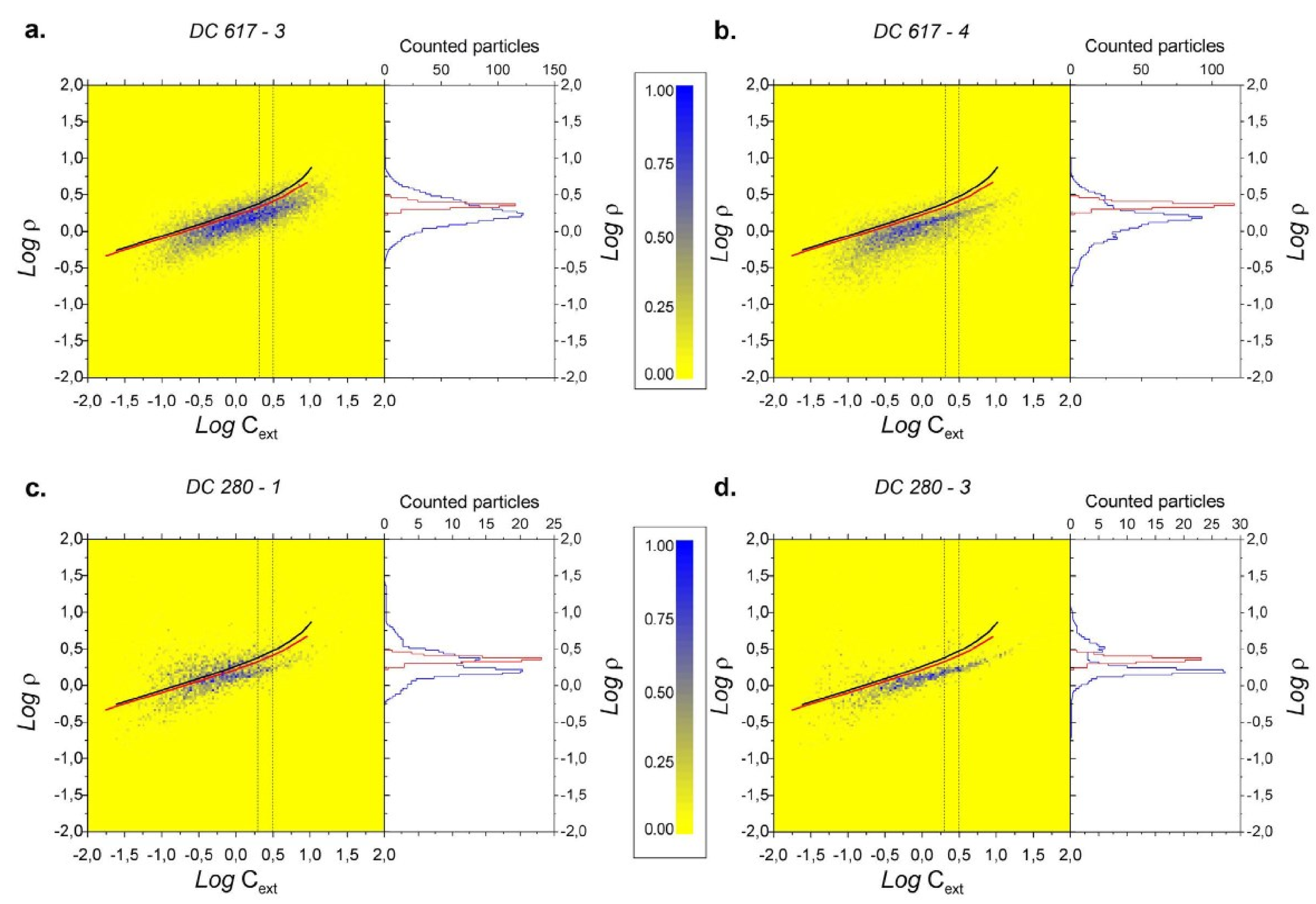
We exploit the novel Single Particle Extinction and Scattering method in connection with shear conditions which give preferred orientations to the particles passing through the scattering volume.
Orienting particles enables to recover the distribution of aspect ratios from the distribution of the optical thickness. The results for water suspensions of calibrated nonspherical particles, polydisperse standard monophasic mineral samples of quartz and kaolinite.

Aggregates of dust grains in ice cores

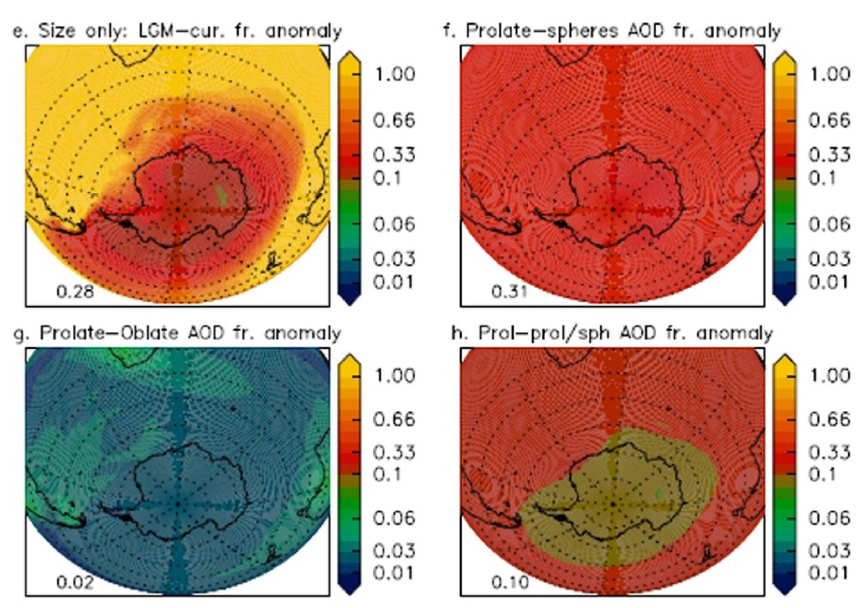
In the deeper part of ice cores, the pristine paleoclimate signal can be altered by in situ formation of dust aggregates, following the relocation of the impurities: aggregate detection is a critical indication for post-depositional processes. While clues for the presence of aggregates have been provided by anomalously large dust size distributions, small aggregates were basically invisible to conventional dust analysis techniques. The SPES method allows to distinguish between compact and non-compact particles through the analysis of samples populated by isometric particles contained in the core samples. It allows for the detection of even the tiniest aggregates, falling within the typical size interval of aeolian mineral aerosol. This approach will potentially provide key evidence for assessing the integrity of paleoclimate records.



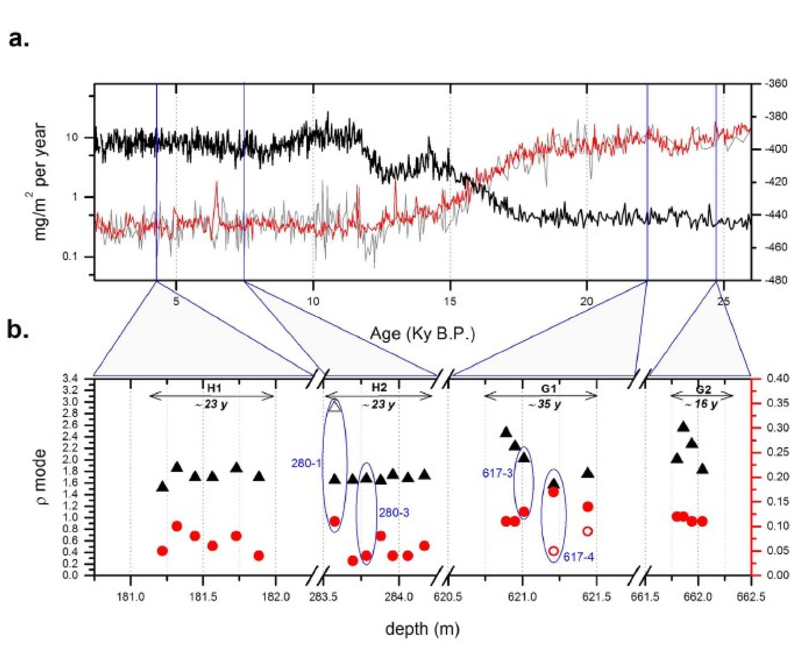
SPES study of *old Dome C* ice core



SPES optical data from the old Dome C ice core represented as the adimensional optical thickness (ρ) versus extinction coefficient (C_{ext}) (µm²). Data are 2D histograms, the color scale indicating the normalized number of particles in each 2D bin. In **a** and **b** two adjacent glacial samples (LGM, ca. 22300 yrs B.P.) are considered (DC-617-3 and DC-617-4 respectively); in **c** and **d** we show two Holocene samples (ca. 7430–7440 yrs B.P.; DC-280-1 and DC- 280-3). Time interval is < 15 years for **a** and **b**, < 10 years for **c** and **d**. Continuous lines represent the expected SPES results for spheres with refractive index n = 1.55 (black) and n = 1.50 (red), very close to the indices of the minerals found in the Dome C ice core. Each plot shows the optical thickness distribution evaluated in the C_{ext} range within the vertical lines which is 2 µm² < C_{ext} < 3.1 µm² (blue SPES data, red spheres).



Effects of the particle size distributions and shapes on dust aerosol optical depth (AOD).
(**e**) Dust AOD anomaly for changes in dust size distributions alone (comparing the LGM vs current size distributions), assuming the dust load of the tuned current climate simulation and spheres (DC-617-3&4). (**f**) Anomaly (expressed as fraction) between the dust AOD for prolate prisms (DC-280-3) with respect to that of spheres, assuming the same dust size distributions for current climate as in (**d**). (**g**) Same as (**f**), comparing the cases with prolate (DC-280-3) and oblate (DC-617-3) prisms. (**h**) Same as (**f**), comparing the cases with prolate (DC-280-3) prisms and a mixture (1:0.6) of prolate prisms and isometric particles (DC-280-1). Numbers in the bottom left corner of panels c-f represent the average value of the respective fields for latitudes < 60 S.



(**a**) EPICA-Dome C stable isotope profile and dust flux records (Coulter Counter in grey, and Abacus in red).
(**b**) Mode (triangles) and standard deviation (circles) of the optical thickness distributions. Experimental errors are comparable to the size of the symbols.

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